Effect of vacuum frying process on the quality of a snack of mango

(Manguifera indica L.)

Efecto del proceso de fritura al vacío sobre la calidad de un pasabocas de mango

(Manguifera indica L.)

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Abstract

The latest trends in consumption of snacks, have led to the search for processes that enhance the quality of snacks. The aim of this study was to observe the behavior of quality parameters of a fried snack made from mango (Manguifera indica L.), using vacuum on a paste of mango pulp and starch, in their preparation. The frying process was carried out using different vacuum pressures (0.4, 0.5, 0.6 bar), temperatures (100, 110 and 120 °C) and times (30, 45, 60, 75 and 90 s). The results showed that the vacuum improves the quality characteristics of the snacks, finding very low fat and humidity contents, lower water activity, texture was according to market demands and a small color variation with respect to paste color. The best treatment was to 0.5 bar, 110 °C y 90 s of immersion time.

Key words: Color, fat, frying, mango, moisture, temperature, texture.

Resumen

El consumo cada vez más creciente de ‘pasabocas’ ha estimulado la búsqueda de procesos para mejorar su calidad. En este estudio se evaluó el comportamiento de los parámetros de calidad de un pasabocas frito hecho con mango (Manguifera indica L.), utilizando vacío sobre una pasta elaborada con este fruto. El proceso de fritura se realizó aplicando diferentes presiones de vacío (0.4, 0.5, 0.6 bar), temperaturas (100, 110 y 120 °C) y tiempos (30, 45, 60, 75 y 90 seg). Los resultados mostraron que el vacío mejora las características de calidad del producto, ya que los contenidos de grasa y humedad fueron muy bajos, la actividad de agua fue menor, la textura fue adecuada para las exigencias del mercado y el color presentó cambios muy pequeños con relación al de la pasta. El mejor tratamiento fue 0.5 bar de presión, 110 °C y 90 seg de inmersión.

Palabras clave: Color, fritura, grasa, humedad, mango, temperatura, textura.
Introduction

Mango (Mangifera indica L.) is a well-known and highly consumed fruit, as fresh fruit, in juices, marmalades and dry snacks (Villamizar and Giraldo, 2010) and different varieties exist like Tommy Atkins, Haden, Manzana, Kent, among others. In 100 g of this fruits there are, in average, 0.7 g of protein, 16.8 g of total carbohydrates, 10 mg of calcium, 13 mg of phosphorus, 0.4 mg of iron, 7 mg of sodium, 189 mg of potassium, 4800 Ul of Vitamin A, 0.05 mg of Thiamine, 0.05 mg of Riboflavin, 1.1 mg of Niacin, and 35 mg of ascorbic.

Frying is a complex process widely used in the food industry. During this process, food is immersed in oil at a higher temperature than the water boiling point in order to produce a vapor contraflow (bubbles) with the oil in the food surface (Bouchon et al., 2003). This process generates products with the organoleptic qualities (color, texture and taste) demanded and appreciated by consumers; however these products have high fat content that is not suitable for human consumption (USDA, 2008). Besides the effects of oil and saturated fat consumption on human health, due to the high temperatures and oxygen exposition during the frying process other effects that are not desirable are present such as degradation of important nutritious components and generation of toxic compounds (acrylamide) in the snack or in the frying oil (Fillion and Henry, 1998). To reduce fat content without losing sensorial qualities, numerous complementary processes or alternatives to the frying process have been proposed (Mellema, 2003; Ziaifar et al., 2008). One of them consists of pressure reduction by working on vacuum to reduce water boiling point in the food and eliminate it at low temperatures (Mir-Bel et al., 2009). It has been proven that besides the reduction on final fat content (Garayo and Moreira, 2002), vacuum frying products have other advantages, like very low acrylamide content (Granda et al., 2004) and better organoleptic and nutritious quality (Shyu and Hwang, 2001; Da Silva and Moreira, 2008; Troncoso et al. 2009).

Frying process implicates simultaneous mass and heat transfer that make important microstructural changes, both in the surface and in the mass of the product. Heat transfer generates protein denaturation, starch gelatinization, water vaporization, crust formation and, color development, which are typical phenomena of the combination effect of multiple chemical reactions. Mass transfer is characterized by the interchange of compounds like water and other soluble materials occluded in the starch, which allows oil penetration in food (Mir-Bel et al., 2009).

Oil absorption is not clearly explained due to the multiple variables involved, such as initial product structure, diverse interchanges between the product and heating media, variation in oil products and properties, chemical reactions, interactions between food compounds and oxidized lipids, and hydrolysis of fats in the frying oil due to humidity (Velasco et al., 2008). The aim of this study was to observe the effect of vacuum frying on the quality of mango snacks (texture, color, humidity percentage, water activity and fat content) in order to define the best conditions (temperature, time and pressure) of the frying process.

Materials and methods

Mango (Mangifera indica L.) of the cultivar Tommy Atkins between 6 and 8 days after harvesting were used. Mangos have 14-15 °brix measured on a table refractometer according to AOAC 932.12, they were coming from Tolima and were bought in the Armenia’s market in Quindio, 1480 MASL and atmospheric pressure 640 mmHg.

Paste characterization and preparation

Selected mangos were characterized during post-harvesting by physicochemical analysis of soluble solids (°brix), humidity percentage (bh), water activity (aw), acidity %, starch content, color and texture.

With the preliminary characterization results, mangos were washed, peeled and manually pulped to get 230 g of pulp that were homogenized on a blender for 1 min to get a puree type of paste. Next, 46 g of starch and wheat flour (4:1) were added and homogenized with the mango puree to fill round molds (2 mm thickness ad 4 cm diameter)
that were refrigerated at 7 °C and HR 21% for 48 h.

**Frying process**

Once the paste was extracted from the mold, it was fried in a machine adapted for that purpose, a metal frame with a 250 ml beaker for oil, a pulley system for immersion and a basket to carry samples was placed on a vacuum oven and the sample was immersed using magnets.

For each test, palm oil on the oven was at process temperatures (100, 110 and 120 °C), then the system was adjusted to the proper vacuum pressure (0.4, 0.5 and 0.6 bar) before the paste immersion and frying was done during specific times (30, 45, 60, 75 and 90 s), kinetic that was used to determine changes in quality characteristics. Snack was taken out and superficial oil was extracted with a paper towel taking into account a ratio paste:oil of 1:15 weight: volume.

Treatments were replicated three times and samples were analyzed by triplicate for humidity percentage (% bh), water activity, color, texture (crunchiness) and fat (%).

**Physico-chemical analysis**

Humidity contents of mango, paste and snack were determined in a vacuum dry oven (J.P Selecta S.A.) according to the method AOAC 20,013, 1980 (A.O.A.C., 1980), in the following way:

\[
\text{humidity(bh)} = \frac{\text{sample weight} - \text{sample dry weight}}{\text{sample weight}} \times 100
\]

Water activity \( (a_w) \) determinations are measured directly at room temperature (between 20 and 30 °C) using a Decagon dew point hygrometer (Aquabotzar 3 TE) with 0.001 sensibility. Color determination was done with a colorimeter (Minolta CR – 10) to evaluate changes in fruit, paste and snack color by the Cielab system, with D65 illuminant and 10° for the observer.

Taking the values for the coordinates \( L^* \) (dark-light), \( a^* \) (green-red), \( b^* \) (blue-yellow) and calculating the color difference in comparison to the paste, represented by \( \Delta E \), according to the following equation

\[
\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2}
\]

where:

- \( L^* \) = \( L \) value for the treatment sample.
- \( L_0^* \) = \( L \) value for the standard sample.
- \( a^* \) = \( a \) value for the treatment sample.
- \( a_0^* \) = \( a \) value standard sample.
- \( b^* \) = \( b \) value treatment sample.
- \( b_0^* \) = \( b \) value standard sample.

To determine the fracturability point for the mango, paste and snack, a texture analyzer (TA. XT. Plus) was used in compression mode with 5 g strength, 3 mm distance and 10 mm/seg speed (fracturability of tortilla chips).

Fat content in paste and snack were determined using a fat detector (DET – GRAS P Selecta) by the DG – 01 (without hydrolisis) method reported on the equipment manual according to the equation:

\[
\% \text{ fat} = \frac{\text{vase weight with fat} - \text{empty vase weight}}{\text{sample weight}} \times 100
\]

**Statistical analysis**

Data for the analysis was organized using Statgraphics Plus 5.1 software (Statgraphics, 2001) to evaluate the effect of the different treatments on the snack characteristics. These effects were guided using ANOVA analysis for one significance (P < 0.05). The experimental design used was an unbalanced factorial design 5x32, with five time levels (30, 45, 60, 75 and 90 s), three temperature levels (100, 110 and 120 °C) and three vacuum pressure levels (0.4, 0.5 and 0.6 bar) with the following model:

\[
Y_{ijs} = \mu + t_i + T_j + P_s + txT_{ij} + txP_{is} + TxP_{js} + txTxP_{tjs} + e_{ijs}
\]

where:

- \( \mu \): general mean.
- \( t_i \): ith time level in seconds.
- \( T_j \): jth temperature level in °C.
- \( P_s \): sth vacuum pressure level in bar.
- \( txT_{ij} \): first order interaction between time and temperature.
- \( txP_{is} \): first order interaction between temperature and pressure.
\( T_xP_{js} \): first order interaction between temperature and pressure.

\( txT_xP_{ij}_s \): second interaction between the three factors.

\( \varepsilon_{ij}_s \): experimental error associated with the three factors.

Additionally, for comparison, Tukey’s test at 95% was done.

**Results and discussion**

**Fruit characterization**

Analysis showed that mango fruits used in this study had water content in fresh pulp of 87.45 ± 2.15%, water activity of 0.986 ± 0.003, °brix 14.26 ± 0.38, cutting force of 3.93 ± 0.060 kgf, a fat content of 0.00169 ± 0.00018%, results that are similar to the ones found by Stafford (1983).

**Snack characterization**

ANOVA results for all the snack variables studied are presented on Table 1. It is observed that the relation of the factors with those variables is significant, meaning that from this analysis there is not an ideal treatment that can be define as the best. For this reason, each one of the snack physico-chemical properties was analyzed separately in relation to the change in vacuum pressure done in each treatment.

**Humidity content**

Results showed that pressure, temperature and time of each treatment affected snack humidity content (\( P < 0.05 \)) in the different vacuum pressures evaluated (Figure 1 a, b, c). For each one of the treatments, humidity content was reduced when the vacuum pressure was increased (a, b, c), the same happened when temperature and frying time were increased.

Initially, water loss celerity was high due to its content on the snack surface, but it was accelerated with vacuum pressure increase due to the rise on strength. However, with longer frying times humidity loss was slower due to, in part, the microstructural changes that happen at the beginning of pressurization that affect the water release from the surface. Additionally, because of the initial dryness (refrigeration) a low concentration of available water is presented and crust formation makes a higher resistance to the water escape (Mariscal and Bouchon, 2008).

**Water activity \((a_w)\)**

In table 1 is shown the effect of the vacuum pressure and temperature on the \( a_w \) (\( P < 0.05 \)), whereas the time effect is low (\( P >

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Fat content (%)</th>
<th>Humidity content (%bb)</th>
<th>( \Delta E )</th>
<th>Cut point (kgf)</th>
<th>( a_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>0.0002</td>
<td>0.0000001</td>
<td>0.0001</td>
<td>0.0059</td>
<td>0.0000001</td>
</tr>
<tr>
<td>Pressure</td>
<td>0.00000003</td>
<td>0.0000002</td>
<td>0.0000002</td>
<td>0.0005</td>
<td>0.0000001</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.0000001</td>
<td>0.0000001</td>
<td>0.0000001</td>
<td>0.0049</td>
<td>0.00000005</td>
</tr>
<tr>
<td>Time</td>
<td>0.0002</td>
<td>0.0119</td>
<td>0.1008</td>
<td>0.0109</td>
<td>0.1329</td>
</tr>
<tr>
<td>Pressure x temp.</td>
<td>0.0000001</td>
<td>0.0000001</td>
<td>0.0000001</td>
<td>0.0000003</td>
<td>0.00000002</td>
</tr>
<tr>
<td>Pressure x time</td>
<td>0.0231</td>
<td>0.0000001</td>
<td>0.0003</td>
<td>0.0002</td>
<td>0.0000001</td>
</tr>
<tr>
<td>Temp. x time</td>
<td>0.0021</td>
<td>0.1649</td>
<td>0.0716</td>
<td>0.0022</td>
<td>0.0000001</td>
</tr>
<tr>
<td>Pressure x temp. x time</td>
<td>0.1473</td>
<td>0.1309</td>
<td>0.0074</td>
<td>0.024</td>
<td>0.00000002</td>
</tr>
<tr>
<td>Best treatment</td>
<td>0.6-110-60</td>
<td>0.6-120-75</td>
<td>0.5-110-45</td>
<td>0.5-110-90</td>
<td>0.5-110-90</td>
</tr>
<tr>
<td>Worst treatment</td>
<td>0.5-100-30</td>
<td>04-100-30</td>
<td>0.6-120-90</td>
<td>0.4-110-90</td>
<td>0.4-100-30</td>
</tr>
</tbody>
</table>

\( P < 0.05 \) significant, reliability of 95%.

\( P < 0.01 \) highly significant, reliability of 99%.
0.05). In Figure 2 is shown the water activity behavior of the fried snack in each one of the treatments. The observed levels are relatively low which favors product preservation impeding oxidation and proliferation of harmful microorganisms, also these levels decrease with temperature increases and tend to stabilize with the time. Similarly, even if water activity reaches low levels changes in vacuum pressure do not have an effect in its variation, which could be due to the fact that in the vacuum frying process the boiling water temperature decreases (Mir-Bel et al., 2009) eliminating high volumes of free water.

Figure 2. Water activity in mango Tommy Atkins snacks under three vacuum pressures and times x variable temperatures.
Color

Snack color was affected by temperature and vacuum pressure ($P < 0.05$); but this was not due to the kinetics originated by temperature and time ($P > 0.05$) (Table 1). Color changes ($\Delta E$) in comparison to the ones of the paste for each treatment are shown in Figure 3. Changes are represented by $\Delta E$ increments that have a slight variation due to relatively low working temperatures in the vacuum pressure treatments that reduce the Amadori products which favors melanoids. In fried food under atmospheric pressure, darkening is notorious since it requires temperatures $> 150 \ ^\circ C$ (Pokorny, 1999), showing chemical

![Color 0.4 bar](image)

![Color 0.5 bar](image)

![Color 0.6 bar](image)

**Figure 3.** Color changes in mango Tommy Atkins snacks under three vacuum pressures and times x variable temperatures.
changes that generate acrylamide (Fillion and Henry, 1998). Vacuum frying process prevents formation of acrylamide and compounds that causes dark colors following Maillard’s reaction, because of the reduction oxidation during the process (Da Silva and Moreira, 2008).

**Texture**

This characteristic was affected by the applied treatments ($P < 0.05$) (Figure 4). As result of changes in vacuum pressure, texture showed a high variability in the different treatments, this difficult the determination of its influence in the reduction of the strength needed to break the snack showing variation when time

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**Figure 4.** Texture changes in mango Tommy Atkins snacks under three vacuum pressures and times x variable temperatures.
and temperature are increased. This is the result of fast gelatinization of starch granules in contact with hot oil and the transformation of its superficial structure in a crunchy crust (Pokorny, 1999).

**Fat content**

Vacuum pressure, temperature and time during the frying process affect fat content ($P < 0.05$). In Figure 5 is shown that while vacuum pressure and temperature increment, fat content reduces and stabilizes during the process. Fat content behavior in the snack has two phases. In the first one, frying, high temperatures causes a partial evaporation of water removed from the snack interior being partially replaced by oil; this evaporation is

![Fat content 0.4 bar](image1)

![Fat content 0.5 bar](image2)

![Fat content 0.6 bar](image3)

**Figure 5.** Fat contents in mango Tommy Atkins snacks under three vacuum pressures and times x variable temperatures.
intense since the vacuum pressure increases the speed of mass and heat transfer resulting on a water boiling temperature decrease (76 to 86 °C). The second phase, pressurization, happens when the snack is removed from the oil increasing quickly pressure and temperature in the pores; this generates oil adherence to the snack surface and oil penetrance in the snack (sponge effect) until the pressure in the pores equals the atmospheric pressure (Troncoso et al., 2009).

**Best treatment**

Best treatment combinations for each vacuum pressure related to the evaluated characteristics are included in Figure 6. The best results for texture, water activity and color happen at vacuum pressure of 0.5 bar (0.5 bar), whereas for fat and humidity content is at 0.6 bar (-0.6 bar); this means that a vacuum pressure of 0.4 bar is too low for getting a snack with good characteristics. The fat content difference at 0.5 bar vs. 0.6 bar.

![Figure 6](image-url)

Figure 6. Best treatment combinations for mango Tommy Atkins snacks under three vacuum pressures and times x variable temperatures.
bar was not significant, the same happened with the humidity content at 0.5 bar vs. 0.6 bar, meaning that the best vacuum pressure treatment corresponds to 0.5 bar, 110 °C temperature and immersion time of 90 sec.

**Conclusions**

- Vacuum pressure positively affects the quality characteristics of fried snacks of mango resulting crunchy, with good color and similar to the fruit, with low fat content and adequate humidity for its conservation.
- The best characteristics for the fried snack were color (ΔE = 19 ± 1.5635), texture (fracturability strength = 0.25637 ± 0.005736), fat content (%fat = 9.4995 ± 0.8744), humidity content (%humidity bh = 1.25 ± 0.3037) and water activity (aw = 0.342 ± 0.0014), obtained with a vacuum pressure of 0.5 bar, temperature of 110 °C and immersion time of 90 s.
- Snack characteristics are better than the traditional snack characteristics which have humidity content lower than 4% and fat content lower than 30% (Rodríguez et al., 1999)

**References**


